Proposed for Presentation at
The Annual Conference on Fire Research
Gaithersburg, MD, October 28-31, 1996

Fuel Temperature Distribution and Burning Rate in Large Pool Fires*

Louis A. Gritzo, Edward A. Boucheron
Unsteady and Reactive Fluid Mechanics, Department 9116
Sandia National Laboratories, P. O. Box 5800
Albuquerque, NM 87185-0836

Doug Murray
Code 528220D
Naval Air Weapons Center
China Lake, CA 93555

Many scenarios of interest in fire science and fire safety involve the burning of liquid fuels in the form of large, fully turbulent (i.e. > 1.3 m diameter) fires. Included in these scenarios are instances where the fuel forms a pool which can be considered as "thermally deep", i.e., the fuel layer is of sufficient depth that thermal penetration is confined to an upper layer and, therefore, the substratum does not interact thermally and has a negligible effect on the fire. Examples include the burning of fuel in an open tank during an industrial accident, burning from a fuel-filled pit as a consequence of a transportation accident, and the gathering and subsequent burning of crude oil on the surface of a waterway for environmental impact mitigation. Other relevant scenarios, not thermally deep, include cases where fuel is spilled and spreads to form a thin liquid layer on a impermeable surface such as a concrete runway, aircraft carrier deck or facility floor. If the surface is flat and the spill is continuous, the mass flow rate of the spill and the mass flux of vapor from the pool surface combine to define the size and duration of the resulting fire.

Large pool fire scenarios are often roughly characterized by the maximum total chemical heat release rate given by $\dot{Q} = \dot{M}_{avg} H_c$, where $\dot{M}_{avg}$ is the average fuel vaporization rate and H_c is the fuel heat of combustion. The total heat release rate defines an important upper limit on the thermal potential of the fire and limited success has been achieved in estimating large fire hazards based on this quantity [1]. The actual thermal hazard large fires pose to critical systems and personnel is determined by the heat flux from the fire to the object of interest. The heat flux distribution within the fire and the distribution of radiative heat flux from the exterior of the flame zone are both strongly affected by the efficiency of combustion within the flame zone. Variations in combustion efficiency are possible due in part to the spatial distribution of fuel which is vaporized from the surface of the liquid and the subsequent transport and mixing of the gaseous fuel with air.

Measurements of fuel vaporization rates and fuel temperature distributions were recently performed as part of a series of large (18.9 m diameter) JP-8 pool fire experiments at the Naval Air Weapons Center (NAWC) CT-4 test facility at China Lake. This work is of particular interest since the majority of the studies performed to date are limited to fires with diameters significantly smaller than the lower limit of the fully turbulent regime. Several important distinguishing features are noted between the mechanisms present in the previous studies and those present in the large fires discussed here. The difference in these mechanisms is primarily due to the magnitude and distribution of the heat flux to the fuel surface. Smaller fires are characterized by spatially uniform heat fluxes to the fuel surface of approximately 30 kW/m^2 [2,3]. Data acquired from large pool fires [4] shown significant variations in the heat flux to the fuel surface with values ranging from 20kW/m^2 near the oxygen-starved interior, to fluxes of 100kW/m^2 directly below the primary flame zone.

---

*This work was supported by Defense Nuclear Agency and the Sandia Engineering Sciences Research Foundation and was performed at Sandia National Laboratories, Albuquerque, NM, managed by Lockheed-Martin Corp. for the U.S. Department of Energy under Contract DE-AC04-94AL85000

Data were acquired at locations of high and low heat flux for each of eight tests with wind conditions ranging from 1.3 m/s to 10.9 m/s. The same general trends were observed in all of the data sets. Inspection of the data reveals the following:

- After the initial transient associated with fire growth (~60 s), the fuel recession rate is steady and equal to 4.4 mm/min; the same value was reported by Blinov and Khudyakov [5] for burning of kerosene and gasoline in 9 m and 23 m diameter fires.
- Heating of the fuel is limited to the top 1.5 cm (which greatly exceeds the penetration depth for pure 1-D conduction).
- The heated depth appears to be slightly greater in regions of reduced heat flux.
- The temperature at the free surface of the fuel is spatially uniform and approximately 510K (nearly equal to the mean of the distillation curve for JP8).
- There are very significant fluctuations observed in the data which increase in magnitude near the fuel surface.

The preceding trends, in conjunction with the distributions of heat flux to the fuel surface observed in previous studies, imply lateral mixing of the liquid fuel primarily due to the maintenance of a free surface in the presence of a non-uniform heat flux distribution. In addition, the potential exists for convection resulting from uneven heating. The construction of a submodel suitable for fire field model implementation depends on the extent to which lateral transport occurs, between the limits of "well-mixed" and "non-mixed". Reduced-scale experiments with well-defined uniform and non-uniform heat flux distributions, complemented by Fourier Transform Infrared (FTIR) measurements of fuel radiative properties, are presently underway to satisfy these requirements.

For large, fully turbulent fires, the heat flux distribution to the fuel surface, which affects the fuel gasification rate and the transport of gaseous fuel within the fire, is strongly influenced by scenario-specific parameters such as; fuel type, fuel pool shape, wind, topology in the neighborhood of the fire, and the presence of engulfed and nearby objects. Present fire field models are capable of representing the effect of varying these parameters on fire behavior in reasonable detail. With improved understanding and quantification of the dominant physical mechanisms governing the burning of liquid fuels in large fires, phenomenological models of the fuel pool thermal transport and gasification processes can be developed for use in numerical simulations. The end goal is to improve the fidelity of fire simulations through physically based models which are validated with full-scale data.

<u>References</u>

1. Mudan, K. S. and Croce, P. A. "Fire Hazard Calculations for Large, Open Hydrocarbon Pool Fires," Section 2-4, *The SFPE Handbook of Fire Protection Engineering, First Edition*, National Fire Protection Association, Quincy, MA.
2. Hamins, A., Fischer, J, Kashiwagi, T., Klassen, M.E. and Gore, J.P., "Heat Feedback to the Fuel Surface in Pool Fires," *Combustion Science and Technology,* Vol 97, pp. 37-62, 1994.
3. Inamura, T., Saito, K., and Tagavi, K.A., "A study of Boilover in Liquid Pool Fires Supported on Water. Part II: Effects of In-depth Radiation Absorption," *Combustion Science and Technology*, Vol. 86, pp. 105-119, 1992.
4. Gritzo, L.A., Nicolette, V.F., Tieszen, S.R., and Moya, J.L. "Heat Transfer to the Fuel Surface in Large Pool Fires," *Transport Phenomenon in Combustion*, S.H. Chan, ed, Taylor and Francis, 1996.
5. Blinov, V.I., and Khudyakov, G. N. "Diffusion Burning of Liquids," English Translation: U.S. Army Engineering Research and Development Labs, Fort Belvoir, VA, Report AERDL-T-1490-A, 1961.